Hillslope Erosion Processes after High Severity Wildfires, Colorado Front Range

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Abstract

Post-fire erosion and sedimentation are of considerable concern because of the adverse effects on flooding, water quality, and aquatic habitat. The primary goal of this study was to assess hillslope and rill erosion rates in severely-burned areas. Erosion rates were measured on 11 planar hillslopes and 20 convergent swales using sediment fences. Mean sediment yields in swales exceeded 1.0 kg m^{-2} for individual storms with a maximum 30-minute intensity of at least 40 mm/hr. On average the swales produced approximately 7 times more sediment per unit area than the planar hillslopes. Rill erosion in the swale axes accounted for approximately 80% of the measured sediment yields.

Introduction

High-severity forest fires can increase soil erosion rates by two or more orders of magnitude with potentially severe consequences to downstream water resources. Previous studies in the Colorado Front Range have shown that most post-fire erosion is driven by high-intensity summer convective thunderstorms in the first 2-3 years after burning (Benavides-Solorio, 2003). Rill erosion may be the dominant source of sediment production in cultivated fields (Govers and Poesen, 1988), but there have been few studies of erosion processes on forested slopes after wildfires. The objectives of this study were to: (1) measure hillslope erosion rates from individual rainstorms; (2) compare unit area erosion rates from planar hillslopes and convergent swales; and (3) compare rill erosion rates in swale axes to measured sediment yields. An improved understanding of erosion processes is needed to better predict post-fire erosion rates and design effective rehabilitation treatments.

Methods

Sediment fences were installed on 31 sites that burned at high severity in the Hayman fire in June 2002. Eleven fences are situated on planar hillslopes (Figure 1) with contributing areas ranging from 35 to 220 m^2. Twenty fences are in convergent swales (Figure 2) with contributing areas of 110 to 6500 m^2. Rainfall amounts and intensities are being measured with four tipping bucket rain gages.

Figure 1. Sediment fence on a planar hillslope.

Figure 1. Sediment fence in the axis of a swale.

Rill erosion is being assessed by repeated measurements of 6-12 cross-sections spaced 2-10 m apart in the axes of 11 swales (Figure 4). The changes in cross-sectional area are multiplied by the length of each segment and the soil bulk density to estimate the mass of sediment (kg) generated from rill erosion. The calculated rill erosion is compared to the mass of sediment captured in the sediment fences after each storm.

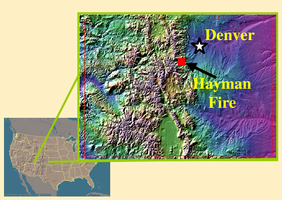

Figure 3. Location of the study area.

Figure 4. Pin frame used to measure rill incision.

Results

Five rain events generated sediment in 2003. Fifty-eight percent of the sediment collected in 2003 was eroded during a 16-mm rainstorm on 11 August. For individual storm events, over half of the variability in erosion rates between sites can be explained by rainfall erosivity (R^2 = 0.53, $p < 0.0001$) (Figure 5). Mean sediment yields exceeded 1.0 kg m^{-2} at rainfall erosivities greater than 200 MJ mm ha^{-1} h^{-1}. Data from all five events indicate a sediment production threshold of approximately 17-20 MJ mm ha^{-1} h^{-1}. When normalized by contributing area and rainfall erosivity (Figure 6), sediment production was 63-92 % higher in swales than on planar hillslopes ($p \leq .06$ for all storms).

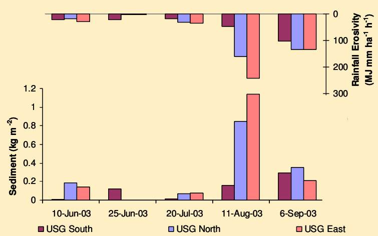

Figure 5. Rainfall erosivity and mean sediment production rates for five storm events from three different areas within the Hayman fire.

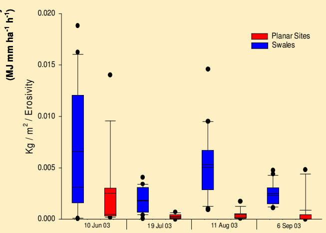

Figure 6. Comparison of erosion rates from swales versus planar hillslopes for four storm events. Values are normalized by contributing area and rainfall erosivity.

Rill incision in the swale axes accounted for approximately 80% of the sediment generated by the large storm on 11 August (Figure 7a). Composite data from all five sediment-producing events also indicate that rill erosion can account for about 80% of the accumulated sediment (Figure 7b). However, the relative importance of rill erosion was highly variable, especially for the three smaller storms in June and July. For these storms the estimated rill erosion exceeded the measured sediment in 11 of the 16 swales that produced sediment, and there was tremendous variability in the ratio of rill erosion to sediment production between swales. For the two large events in August and September the estimated rill erosion exceeded the measured sediment in only 2 of the 23 swales that produced sediment, and the variability in the ratio between rill erosion and sediment production was much less than for the smaller storms.

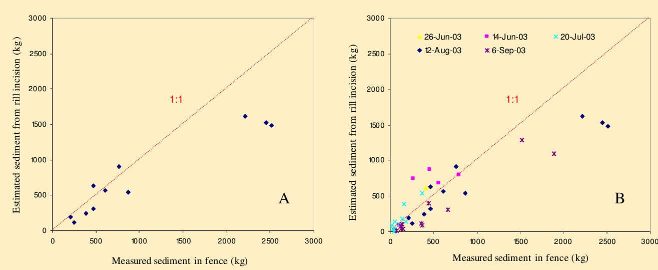

Figure 7. Estimated rill erosion from cross-sectional measurements versus the sediment collected in the sediment fences for (a) the 16 mm storm on 11 August and (b) all storms.

Within each swale there was considerable variability in the rill incision rate between cross-sections. For example, in swale 17 the incision resulting from the 11 August storm varied from 68 cm^2 in cross-section 3 (Figure 8a) to 274 cm^2 in cross-section 2 (Figure 8b). The rill erosion estimated from the 12 cross-sections in swale 17 accounted for 60% of the 2500 kg excavated from the sediment fence after this storm.

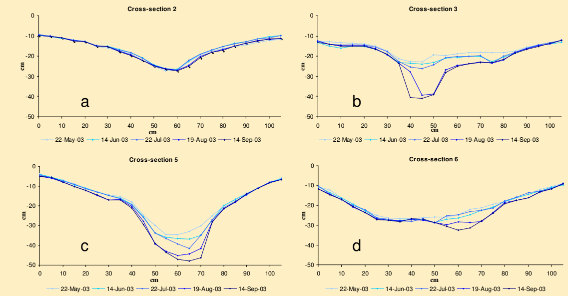

Figure 8. Erosion in selected cross-sections over time from the top of swale 17 (a) to the bottom (d). In all cases the rill deepened with each successive storm (gradations from light blue to dark blue) but the rate of incision varied between cross-sections.

Discussion

The results from this study agree with work on the Bobcat fire near Fort Collins, where swales produced 2-3 times more sediment per unit area than planar hillslopes (Benavides-Solorio, 2003). Similarly, research after the Buffalo Creek fire showed that approximately 85% of the total sediment yield was due to the incision of rills and low-order channels (Moody and Martin, 2001).

The large differences in incision rates between cross-sections (Figure 8) emphasize the spatial variability in erosion rates and processes within individual rills. The data suggest that in the larger events there may be more overland flow and erosion on the sideslopes, while in the smaller events rill incision can account for nearly all of the measured sediment.

Rill incision occurred in all of the swales with monitored cross-sections. Smaller rills appeared on two of the eleven planar hillslopes, and the unit area sediment production rates from these two hillslopes was approximately 18 times higher than from the nine planar sites with no evidence of rill erosion.

Conclusions

Post-fire erosion in the Colorado Front Range is driven by localized, high-intensity summer rainstorms. Unit-area erosion rates averaged seven times higher in swales than on planar hillslopes. Topographic convergence in swales leads to more concentrated overland flow, increasing local shear stress and causing rill incision in swale axes. On average, the calculated rill erosion can account for approximately 80% of the measured sediment production. The identification of convergent areas as the primary sediment source after wildfires should help in the design and application of more effective rehabilitation treatments.

Acknowledgements

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Literature Cited

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